Nickel Removal by the Aquatic Plant (Ceratophyllum Demersum L.)

M. Chorom, A. Parnian, and N. Jaafarzadeh

***Abstract*—Phytoremediation with aquatic plants is a new, effective and inexpensive method for improving water quality and wastewater. In this study, Nickel removal by the aquatic plant, coontail (Ceratophyllum demersum L.), native hydrophyte of most of Iran's rivers, was reviewed after optimum growing pH nomination, within 14 days cultivation in contaminated Hoagland nutrient solution, at the four different concentration of nickel (0, 1, 2, 4, and 6 mg L^{-1}). With daily analysis of nickel concentration in cultivation solution and also initial and final concentration of this element in plant, nickel phytoextraction potential evaluated, and nickel biological effects on coontail grows with biomass production was studied. Maximum removal efficiency was 50% calculated from 6 mg L^{-1} metal concentration. Maximum bioconcentration factor and maximum uptake index calculated from 6 mg L^{-1} metal concentration were 338.65 and 5.05 mg, respectively. Maximum (3.6 g/day) and minimum (1.27 g/day) biomass production index caused from 0 mg L^{-1} and 6 mg L^{-1} of pollutant concentrations. Based on the results, nickel phytoremediation of industrial wastewater by coontail is applicable.**

***Index Terms*—Nickel, wastewater, phytoremediation, aquatic plant.**

I. Introduction

Industrialization in developing countries has contaminated the environments by heavy metals, where advance treatment technologies are neither available nor affordable [6]-[11]. Environmental exposure to toxic heavy metals is one of the main critical issues on environmental and public health [9]. Heavy metals are common pollutants in aquatic ecosystems. These ecosystems are particularly susceptible and often final receptor of heavy metals [9]. These ecosystems are sensitive to pollutants due to the presence of relatively small biomass in a variety of trophic levels, which may lead to accumulation of heavy metals. Hence, hydrophytes are often the first link in relation to metal contents of aquatic environments.

Environmental exposure to toxic trace elements is one of the main critical issues on environmental and public health [9]. Ni is an essential trace element for plants an ecosystems survival in low concentration [2]. Ni exceeding its critical level might bring about serious lung and kidney problems except from gastrointestinal distress, pulmonary fibrosis and skin dermatitis [5]-[7]. And it is known that Ni is human carcinogen [7].

Several health hazards caused by heavy metals and many technologies have been used for their removal from aquatic medium, including membrane filtration (like: reverse osmosis [19] and electro dialysis [22], ion exchange [2], ion adsorptive membrane [24], bioreactor system [13], adsorption (like: carbon nanotubes [23] and activated carbon [1], chemical precipitation [15], addition of chemical substance [8], catalytic reduction [6] and many other ones we do not mention them.

Phytotechnology is an emerging technology that has a potential to treat a wide range of contaminants for a lower cost than traditional technologies. This technology uses various types of plants to degrade, extract, contain, or immobilize contaminants in soil and water. Phytotechnology has been used for remediation of chlorinated solvents, metals, explosives and propellants, pesticides, polycyclic aromatic hydrocarbons, radionuclides, and petroleum hydrocarbon compounds (USEPA, 2000). Hydrophytes (aquatic macrophyte) are known to heavy metals accumulators and being for phytoremediation [3]. Aquatic phytoremediation of metals from aqueous environments is very promising area, and several highly efficient examples have shown the applicability of this process to clean industrial waste streams, to preserve drinking water and aquatic biodiversity.

Ceratophyllum demersum L. (hornweed or coontail) grows fast in shallow, muddy, quiescent water bodies at low light intensities [4]. It is a submerged, rootless, free floating, perennial and is cosmopolitan in distribution. This submerged macrophyte has a high capacity for vegetative propagation and biomass production even under the modest nutritional conditions. It is useful as an oxygenator for use in the Closed Equilibrated Biological Aquatic System (CEBAS). *C. demersum* can be biofilter for heavy metals, such as Cd [4], [16], [18], Pb [17], [21] and Ni [11].

The objective of this study was to examine the capability of aquatic macrophyte *Ceratophyllum demersum* for the removal of heavy metal, Ni (II) from aquatic mediums.

II. Materials and Methods

A. Stock Cultures

Ceratophyllum demersum L. is commonly available aquatic macrophyte in Ahwaz Rivers, Khuzestan province, Iran. Cultures of *C. demersum* (were obtained from irrigation dike of Shahid Chamran University) and grown in nursery in 30-L plastic containers filled with half-strength Hoagland's nutrient solution [14]. The plants were cultivated under these conditions for 4 weeks prior to the beginning of the experiments. The nutrient solution with pH = 7.0 was replaced after each 3 days. Preliminary tests for pH were performed to determine the appropriate best pH range for test plant grows and metal accumulation.

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Mostafa Chorom and Amir Parnian are with the Department of Soil Sciences, Shaid Chmran University, Ahvaz, Iran (email:mchorom@yahoo.com).

Nematollah jaafarzadeh is with the Department of Environmental Health Engineering, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran.

B. Experimental Setup

Eight-day batch experiments were conducted to evaluate Ni removal by *C. demersum*. The experiments were performed in nursery in 3-L plastic receptacle (surface area: 432cm^2). Therefore, Ni concentrations selected were 0.00, 1.0, 2.0, 4.0 and 6.0 mg L^{-1}. For each concentration of contamination, three replicates treated, and three receptacles without plants were set as controls. Each replica was filled with 1.8 L of half-strength Hoagland's nutrient solution contaminated with separate contamination of Ni.

The pH of the solutions was adjusted with 0.01 M NaOH and 0.01 M HCl to be 7.0. Every day during cultivation the evaporated volume was replaced with deionized water.

Twelve grams fresh weight (FW) of plants was added to each treatment replicate. Treatment and control vessels were randomly arranged. The water sampling period was 1, 2, 3 ... and 14 day after the start of heavy metal application. After 14th day, the experiment was stopped and the plants were washed three times with distilled water then, the fresh weights and dry weights (24 h at 70 ◦C) of plants were measured.

C. Biomass Production Measurements

Plant biomass production *Pr* (g $_{FW}$ d^{-1}) was calculated as follows:

$$Pr = (FW_2 - FW_1)/\Delta t, \tag{1}$$

where FW_1 and FW_2 are plant fresh weight (g) at time 1 and time 2, respectively, and Δt is the difference between time 1 and time 2 (days).

D. Heavy Metal Analysis of Plant and Water Samples

Plants dried samples were dissolved in 4 M HNO_3 and, residues digested in 1 M HCl. After digestion the metal was determined by Atomic Absorption Spectrophotometer (Unicam 939 Germany) after acidification of the sample with 2% HCl. Control samples were also treated by the same way.

E. Removal of Heavy Metals by Plants

Removal was determined by quantifying the concentration of metal left in the medium after incubation with plants. Water samples of 2 ml were taken daily from the vessels in order to measure heavy metal concentration removed from the nutrient solution. Removal of metals was calculated using the following equation [11]:

$$R\,(\%) = [(C_0 - C_t)/\ C_0] \times 100 \tag{2}$$

where C_0 and C_t represent the residual concentration of metal at the beginning of the experiment and at time of t, respectively.

F. Bioconcentration Factor

The bioconcentration factor (BCF) was calculated as follows [12]:

$$BCF = \text{metal in plant biomass (mg Kg}^{-1}) \,/\, \text{metal in solution (mg L}^{-1}) \tag{3}$$

G. Uptake Index

The Uptake index was calculated as follows:

$$\text{Uptake index} = \text{metal in plant biomass (mg Kg}^{-1}) \times \text{plant biomass (Kg)} \tag{4}$$

III. Results and Discussion

A. Ni Removal from Water

Phytoremediation, a method to remove pollutants from the environment by using plants and algae, has been known as a promising cost-effective and environmentally sustainable technology for the remediation of water polluted by toxic trace elements [20]. Table I shows the percentage of Ni removal for different initial concentrations by *C. demersum*. The initial Ni concentrations were analyzed using the atomic absorption method and the values were similar to the nominal concentrations selected in this study. The results revealed high percentage nickel efficiency (52.5%) when the metal was initially present in the nutrient medium at approximately 4 mg L^{-1}. [15] Used *Lemna gibba L.* and [18] used *Spirodela polyrrhiza* for the simultaneous removal of heavy metals in laboratory experiences respectively along 7 and 15 days. When metal concentration respectively was 50 mg L^{-1} and 2 mg L^{-1}, the metal removed percentages were, 53.5% and 71%. The results [10] showed that submerged aquatic plant *C. demersum* can be successfully used for heavy metals (Pb, Zn and Cu) removal under dilute metal concentration. With other macrophytes (*Spirodela polyrrhiza*, *Pistia stratiotes*, and *Eichhormia cressipes*), [18] the metals (Ni and Cd) during 15 days removed percentages in sequences were, over 45%, and more than 50%. The Ni concentration of 6 mg L^{-1} for *C. demersum* (Fig. 1) was chosen to determine the equilibrium time of heavy metal uptake.

TABLE I: Nickel Removal Efficiency and Metal-Uptake for Different Initial Ni Concentrations by *C. demersum*

Metal concentration in solution (mgL^{-1})	6	4	2	1
Final concentration by *C. demersum* (mgL^{-1})	3.50	2.00	0.95	0.5
Removal by *C. demersum* (%)	41.7	50	52.5	46
Coontail Ni-Uptake Index in plants (mg)	0.82	1.89	3.6	4.5

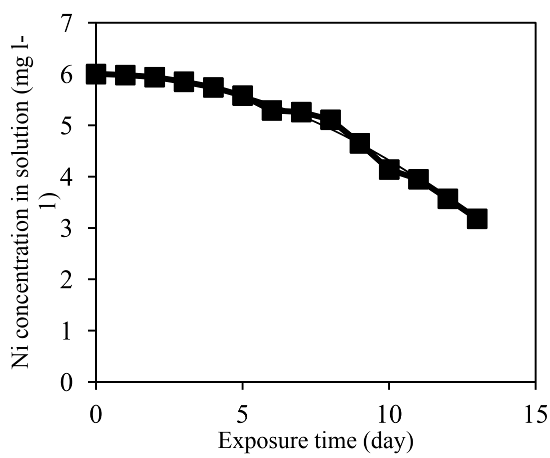

Fig. 1. Nickel concentration in the nutrient medium versus time *C. demersum* was exposed to 6 mg L^{-1} of Ni during 13 days.

Time dependency was conducted in order to determine how long the plants would take to accumulate and remove the metal from water. Analysis of Ni concentrations in water with increasing time showed that the Ni concentration decreased up to 13th day for *C. demersum* (Fig. 1) during the treatment. Over these times, metal concentration in water reached a constant value where no more Ni was removed from the nutrient solution. Ni removal can be described by the following equation:

$$Y = 0.0138t^2 - 0.3471t + 5.7861, \quad R^2 = 0.99; \qquad (5)$$

Y is the metal concentration in water (mg L^{-1}) and t the time of treatment (day).

According to the equation when plant grows more it can accumulate more Ni (II) in its body.

B. Metals Accumulation in Plants Biomass

The Ni concentration in *C. demersum* increased with increasing initial concentration in the contaminated Hoagland nutrient solution. The metal amount accumulated in coontail was 56.22, 154.29, 400 and 562.5 mg Kg^{-1} DM. when the medium was respectively supplied with 1, 2, 4 and 6 mg L^{-1} of Ni. To quantify metal accumulation in plant biomass, the bioconcentration factor (BCF) is more significant than the amount accumulated in plants since it provides an index of the ability of the plants to accumulate metal element with respect to the element concentration in water [12]. The Ni BCF value for *C. demersum* between 104.16 and 200; the highest value was attained at 4 mg L^{-1} (Fig. 2). It is important to note that plant showed reduced biomass when grown in contaminated water with 1.00 - 6.00 mg L^{-1} of metal Ni, but did not die from phytotoxicity. According to [20], plant which is considered as a good accumulator, must have a BCF over 1000, thus we cannot considered *C. demersum* as a good accumulator for Ni^{2+}. And To better quantifying metal accumulation in plant biomass we calculated plant metals uptake shown in Table I. The Ni uptake value for *C. demersum* between 0.82 and 4.5 (all of values calculated for 1.8 L contaminated solution). The highest value in all treatments was attained at 6 mg L^{-1} of metals contamination and according to these results metal uptake contamination and according to these results metal uptake value in plants for Ni contamination in coontail was considerable.

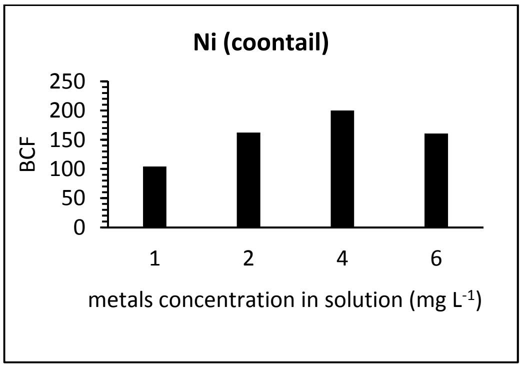

Fig. 2. Effect of heavy metal Ni (II) concentration in solution on the bioconcentration factor (BCF) in coontail.

C. Plants Biomass Production

The results of biomass production are shown in Table II.

Mean biomass production in the cultivation period observed less biomass production than control (3.6 g FW d^{-1}), varied between 1.27 and 2.26 g FW d^{-1}.

TABLE II: PERCENTAGE OF NI EFFECIENCY FOR DIFFERENT INITIAL CONCENTRATION BY *C. DEMERSUM*

Initial concentration (mgL^{-1})	Ni contaminated treatments biomass production by *C. demersum* (g FW d^{-1})
6	1.27 ± 0.10
4	1.51 ± 0.07
2	1.84 ± 0.21
1	2.26 ± 0.13
Control	3.6 ± 0.19

IV. CONCLUSION

Wastewater, drainage water and industrial wastewater contaminated aquatic medium with toxic and undesirable heavy metals and that is a serious environmental problem. That phenomenon may be solved with phytoremediation techniques, phytoaccumulation and phytoextraction. In the present study, we demonstrated that nickel removal by the aquatic plant, coontail (*Ceratophyllum demersum L.)* copious aquatic macrophyte in the Khuzestan province, southwest of Iran, was effective in removing Ni from the constructed medium. *C. demersum* accumulated heavy metal (4.5 mg Ni from 1.8 L 6 mgL^{-1} Ni contaminated aquatic medium) and very good but in slow removal rate (50% Ni removal) and when plant grows more, with increasing of its biomass, it can accumulate more Ni (II) in its body. Great removal efficiency and high Ni accumulation capacity make *C. demersum* an excellent choice for these heavy metals phytoremediation.

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Prof. Dr. Mostafa Chorom was born in Ahvaz /Iran on 21/3/1359. He is working at the Shaid Chmran University (Ahvaz/Iran) in Soil Sciences Dept. as Academic staff (Lecturer and researcher). Residential address: Koya Ostadan Shaid Chamran Maryam Ave. No. 627 Shaid Chamran Uni. Ahvaz /Iran. Email:mchorom@yahoo.com.

Membership: 1-Soil Science Society of Iran, 2-Senior Member of APCBEES (100501). Educational: BSc at Soil Science in 1984 from Ahvaz University in Iran, MSc at Soil Science in 1986 from Tehran University, Iran. PhD at Soil Science in 1995 from Adelaide University, Australia. Work Experience: He was involved in several field research projects in Soil Chemistry, Soil and Water pollution, River sediments pollution and management of application of Sewage sludge and Wastewater in Agriculturehe has been supervised for more than75 post-graduate students. He was selected for the best supervision of post-graduate student at Shaid Chmran University (Ahvaz/Iran) in 2006, year. Recently publications:

Amir Parnian is PhD student of Shahid Chamran University, Faculty of Agriculture, Department of Soil Science, Ahvaz, Iran.

Professor Nematollah jaafarzadeh is with Department of Environmental Health Engineering, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran.